Electronic Version

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Claims

[c1] A plasma source comprising:

a chamber for containing a feed gas;

an anode that is positioned in the chamber;

a segmented magnetron cathode comprising a plurality of magnetron cathode segments that are positioned in the chamber proximate to the anode, each of the plurality of magnetron cathode segments being electrically isolated from each of the other magnetron cathode segments;

a switch having an electrical input and a plurality of electrical outputs, a respective one of the plurality of electrical outputs being electrically connected to a respective one of the plurality of magnetron cathode segments; and

a power supply having an electrical output that is electrically connected to the electrical input of the switch, the power supply generating a train of voltage pulses that ignites a plasma from the feed gas, individual voltage pulses in the train of voltage pulses being routed by the switch in a predetermined sequence to at least two of the plurality of magnetron cathode segments.

[c2] The plasma source of claim 1 wherein the anode comprises a plurality of anode sections, a respective one of the plurality of anode sections being positioned adjacent to a respective one of the plurality of magnetron cathode segments.

[c3] The plasma source of claim 2 wherein the plurality of magnetron cathode segments and the plurality of anode sections are concentrically positioned.

[c4] The plasma source of claim 1 wherein the anode comprises at least one gas injector.

[c5] The plasma source of claim 1 wherein at least one of the plurality of magnetron cathode segments comprises sputtering target material.

[c6] The plasma source of claim 1 wherein at least one of the magnetron cathode segments comprises a target material that is different from a target material of another one of the magnetron cathode segments.

[c7] The plasma source of claim 1 wherein the plurality of magnetron cathode segments comprises a hollow cathode magnetron.

[c8] The plasma source of claim 1 wherein each of the plurality of magnetron cathode segments is positioned in a

unique horizontal plane.

[c9] The plasma source of claim 1 wherein each of the plurality of magnetron cathode segments is positioned in a unique vertical plane.

[c10] The plasma source of claim 1 wherein at least two of the plurality of magnetron cathode segments have different dimensions.

[c11] The plasma source of claim 1 wherein the switch comprises at least one insulated gate bipolar transistor (IGBT).

[c12] The plasma source of claim 1 wherein the power supply generates at least one voltage pulse in the train of voltage pulses that comprises a rise time and an amplitude that generates a weakly-ionized plasma and a strongly-ionized plasma from the feed gas.

[c13] The plasma source of claim 1 wherein the power supply generates at least one voltage pulse in the train of voltage pulses that comprises a first rise time and a first amplitude that generates a weakly-ionized plasma and a second rise time and a second amplitude that generates a strongly-ionized plasma.

[c14] The plasma source of claim 13 wherein the power supply

generates at least one voltage pulse in the train of voltage pulses that comprises a rise time and a peak amplitude that shifts an electron energy distribution in the weakly-ionized plasma to energies that rapidly increase electron density in the weakly-ionized plasma so that a strongly-ionized plasma is formed.

[c15] The plasma source of claim 1 wherein the power supply generates at least one voltage pulse in the train of voltage pulses that comprises a rise time and an amplitude that generates a strongly-ionized plasma from the feed gas.

[c16] The plasma source of claim 1 further comprising at least two magnets that are positioned proximate to the plurality of magnetron cathode segments.

[c17] The plasma source of claim 16 wherein the at least two magnets generate an unbalanced magnetic field.

[c18] The plasma source of claim 1 further comprising a reactive gas source that is coupled to the chamber, the reactive gas source supplying reactive gas to the chamber.

[c19] The plasma source of claim 1 further comprising an excited atom source that is coupled to the chamber, the excited atom source supplying excited atoms to the chamber.

[c20] The plasma source of claim 19 wherein at least some of the excited atoms supplied by the excited atom source comprise metastable atoms.

[c21] The plasma source of claim 1 further comprising a pre-ionizing electrode that is positioned in the chamber, the pre-ionizing electrode generating a weakly-ionized plasma proximate to the segmented magnetron cathode.

[c22] The plasma source of claim 1 further comprising a controller that is electrically connected to the power supply, the controller determining the predetermined pulse sequence of the individual voltage pulses.

[c23] A method for generating a plasma, the method comprising:

confining a feed gas;

generating a train of voltage pulses;

applying a first voltage pulse in the train of voltage pulses to a first magnetron cathode segment of a segmented magnetron cathode; and

applying a second voltage pulse in the train of voltage pulses to a second magnetron cathode segment of the segmented magnetron cathode that is electrically isolated from the first magnetron cathode segment, at least one of the first voltage pulse and the

second voltage pulse generating a plasma from the feed gas.

[c24] The method of claim 23 wherein the first and the second voltage pulse are not consecutive voltage pulses in the train of voltage pulses.

[c25] The method of claim 23 wherein the first voltage pulse in the train of voltage pulses ignites a weakly-ionized plasma from the feed gas.

[c26] The method of claim 25 wherein the density of the weakly-ionized plasma is less than about $10^{12} cm^{-3}$.

[c27] The method of claim 25 wherein the applying the second voltage pulse in the train of voltage pulses shifts an electron energy distribution in the weakly-ionized plasma to energies that rapidly increase electron density in the weakly-ionized plasma so that a strongly-ionized plasma is formed.

[c28] The method of claim 23 wherein the applying the second voltage pulse in the train of voltage pulses increases a density of the plasma.

[c29] The method of claim 28 wherein the density of the plasma is greater than about $10^{12} cm^{-3}$.

[c30] The method of claim 23 further comprising generating a

magnetic field through the plasma.

[c31] The method of claim 30 wherein the magnetic field comprises an unbalanced magnetic field.

[c32] The method of claim 23 further comprising supplying excited atoms proximate to the segmented magnetron cathode.

[c33] The method of claim 32 wherein at least some of the excited atoms comprise metastable atoms.

[c34] The method of claim 23 further comprising confining a reactive gas and generating the plasma from the reactive gas.

[c35] The method of claim 23 further comprising combining a reactive gas with the plasma.

[c36] The method of claim 23 further comprising applying a third voltage pulse in the train of voltage pulses to a third magnetron cathode segment that is electrically isolated from both the first magnetron cathode segment and the second magnetron cathode segment.

[c37] The method of claim 23 wherein a shape of the first voltage pulse is different than a shape of the second voltage pulse.

[c38] The method of claim 23 further comprising changing at least one of a rise time, a fall time, an amplitude, a pulse width, and a shape of at least one of the first and the second voltage pulse in order to increase a density of the plasma.

[c39] A method for generating a uniform coating on a substrate, the method comprising:

confining a feed gas;

generating a train of voltage pulses;

applying a first voltage pulse in the train of voltage pulses to a first magnetron cathode segment of a segmented magnetron cathode, the first voltage pulse generating a plasma that sputters target material from the first cathode segment onto a surface of a substrate;

applying a second voltage pulse in the train of voltage pulses to a second magnetron cathode segment of the segmented magnetron cathode that is electrically isolated from the first magnetron cathode segment, the second voltage pulse generating a plasma that sputters target material from the second cathode segment onto the surface of the substrate; and

selecting at least one of a rise time, a fall time, an amplitude, a shape, and a pulse width of at least one of the first and the second voltage pulses to achieve

a desired uniformity of sputtered target material on the surface of the substrate.

[c40] The method of claim 39 further comprising generating a magnetic field proximate to the segmented magnetron cathode, at least one of a strength and a shape of the magnetic field being chosen to achieve a desired uniformity of the sputtered material.

[c41] The method of claim 40 wherein the magnetic field comprises an unbalanced magnetic field.

[c42] The method of claim 39 further comprising supplying excited atoms proximate to the segmented magnetron cathode.

[c43] The method of claim 39 further comprising supplying reactive gas proximate to the segmented magnetron cathode.

[c44] The method of claim 39 further comprising increasing a density of the plasma by modifying at least one of the rise time, the fall time, the amplitude, the shape, and the pulse width of at least one of the first and the second voltage pulses.

[c45] A plasma source comprising:

means for confining a feed gas;

means for generating a train of voltage pulses;
means for applying a first voltage pulse in the train of voltage pulses to a first magnetron cathode segment of a segmented magnetron cathode; and
means for applying a second voltage pulse in the train of voltage pulses to a second magnetron cathode segment of the segmented magnetron cathode that is electrically isolated from the first magnetron cathode segment, at least one of the first voltage pulse and the second voltage pulse generating a plasma from the feed gas.